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DIVISION OF ENGINEERING AND IRRIGATION

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BULLETIN No. 12

SUMMARY REPORT

ON THE

Water Resources of California

AND A

Coordinated Plan for their Development

A REPORT TO THE LEGISLATURE OF 1927

By PAUL BAILEY, State Engineer

CALIFORNIA STATE PRINTING OFFICE
CHARLES A. WHITMORE, State Printer
SACRAMENTO, 1927

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Site for Boulder Canyon Dam on Lower Colorado River
Proposed by U. S. Bureau of Reclamation.

TABLE OF CONTENTS.

	Page
LETTER OF TRANSMITTAL	7
LETTER FROM ENGINEERING ADVISORY COMMITTEE	9
PERSONNEL OF ADVISORY COMMITTEES	11
ORGANIZATION	13
FOREWORD	16
Chapter 889 of the Statutes of 1921	18
Chapter 477 of the Statutes of 1925	19
SUMMARY REPORT	21
Water Resources of California	21
Characteristics of a Comprehensive Plan	22
Importance of Orderly Development	24
Necessity of Action	24
Value of Coordinated Development	26
The Coordinated Plan	26
Sacramento Valley	27
San Joaquin Valley	33
Southern California	42
RECOMMENDATIONS	48

MAP OF COORDINATED PLAN 26

LETTER OF TRANSMITTAL

January 1, 1927.

To the Members of the Legislature,
State of California,
Session of 1927.

In accordance with Chapter 477 of the 1925 Statutes, I have the honor to transmit herewith the concluding report on six years of investigation of the water resources and of the present and future requirements for water in California.

As the result of this extensive study, a plan has been prepared for coordinating the development and use of water for all purposes to secure the greatest public advantage. This plan is presented as the most feasible engineering solution for the coordination of the several uses of water and the means by which California may obtain the water necessary for future development.

The plan is very broad in its scope. It deals primarily with the larger areas deficient in local supply that require the importation of water from distant sources for their full development. It is necessarily based upon the beneficial use of all water. It involves many problems of execution that could be considered at this time only to the extent necessary to produce an engineering plan with minimum difficulty in other respects. No attempt has been made to indicate the adjustments that would have to be made with vested rights and existing uses of water. These and other problems are of such complexity and magnitude that their solution can be reached only through the cooperative effort of all those interested in the development of the state. The facts are presented, therefore, in order that the advantages of adopting this coordinated plan may be weighed with the probable cost and other difficulties and appropriate action be taken.

In conclusion it is my desire to call to your attention the great value received by the state from the services of the consultants to these investigations. Eminent in their profession and mature in experience and judgment, these men have given much time from their busy lives at nominal compensation in order that the state may have for its use the best the engineering profession may offer. I am enclosing herewith a letter in which this Committee has expressed a thought pertinent to the coordinated plan so well taken that it should be yours in its original statement.

Respectfully submitted.

Paul Bailey

Director of Public Works.

LETTER FROM ENGINEERING ADVISORY COMMITTEE.

December 30, 1926.

DIRECTOR OF PUBLIC WORKS,
Sacramento, California.

DEAR SIR: After six years of association with the Division of Engineering and Irrigation in the discusson of the problems arising in the investigation of the water resources of California, this Committee feels that it should at least record its good impression of the efficient manner in which the entire program of investigation has been organized and carried out by the Division. Seldom has such an intensive study been made over a long period of time with the thoroughness, efficiency, and complete cooperation of all interests concerned, as has been accomplished in the work described in the accompanying report and its appendices. The plan which has been evolved is one of great magnitude and complexity, serving as it does irrigation, domestic water supply, power development, navigation, flood control, hydraulic mining and the prevention of the encroachment of salt water in the delta of the Sacramento and San Joaquin Rivers.

It is the opinion of the Committee that the results of the studies as set forth will be of exceedingly great value to the future progress of the state. However, the Committee feels that it would be lacking in candor if it did not point out at this time that the value of such a plan depends entirely upon its ultimate completion and operation as outlined, no matter whether constructed by private interests, by the state or federal governments, or by any combination of them.

In order to obtain the benefits of coordination which is the essential feature, it is necessary that the plan be

adopted as a whole and a policy be devised that will insure its progressive execution in harmony with existing, pending, and future local projects, and that when completed, the whole be operated in accordance with the method outlined. With such a policy adopted construction may proceed by units.

Respectfully submitted.

Louis C. Hill
J. B. Lippincott
Wm. Mulholland
A. Kemp Bell
A. J. Cleary
B. A. Etcheverry
F. C. Herrman
W. L. Huber

Members of Engineering Advisory Committee.

PERSONNEL OF ADVISORY COMMITTEES.

This report has been prepared in consultation with a committee of engineers who have advised in the preparation of the "Coordinated Plan." Most of the members have served through the entire six years of investigation. Also, complete cooperation with federal and state offices has obtained through the entire period. In this regard, it is desired to mention, especially, Lieutenant-Colonel U. S. Grant, III, formerly member and secretary of the California Debris Commission and District Engineer, Second District, U. S. Federal Engineers, who made many helpful suggestions. During the last two years, Major C. S. Ridley, member and secretary of the California Debris Commission, successor in office to Lieutenant-Colonel Grant, Mr. F. E. Bonner, District Engineer, U. S. Forest Service, representing the Federal Power Commission in California, and Mr. L. S. Ready, Chief Engineer of the State Railroad Commission, have attended the committee meetings and entered into their discussion. The entire committee membership is

Louis C. Hill
J. B. Lippincott
Wm. Mulholland
A. J. Cleary
G. A. Elliott
B. A. Etcheverry
F. C. Herrmann
Walter L. Huber
A. Kempkey

Cooperating with committee

F. E. Bonner
L. S. Ready
C. S. Ridley

The survey of the water resources of the state, published as Bul. No. 5, "Flow in California Streams," was made in consultation with

C. E. Grunsky
Louis C. Hill
Charles D. Marx
H. D. McGlashan

Estimates of the water required for the full development of the state's resources, published as Bul. No. 6, "Water Requirements of California Lands," were prepared in consultation with

A. N. Burch
B. A. Etcheverry
Samuel Fortier
A. L. Sonderegger

The first report on these investigations rendered to the 1923 Legislature and published as Bul. No. 4, "Water Resources of California," was prepared with the advice of a citizens committee appointed by Governor Stephens, as follows:

J. C. Forkner, *Chairman*
Peter Cook
Jonathan S. Dodge
B. A. Etcheverry
Harry Hawgood
H. A. Kluegel
Robert B. Marshall
H. D. McGlashan
O. B. Tout
U. S. Webb

ORGANIZATION.

The investigation of the water resources of California and the preparation of the reports thereon have been planned, directed and brought to completion by

PAUL BAILEY,

Director of Public Works and Chief of the Division of Engineering and Irrigation.

Acknowledgment of the services rendered by those who assisted in the preparation of previous reports submitted to the Legislatures of 1923 and 1925 has been expressed in those reports.

This, the summary report on the water resources of California and a coordinated plan for their development, has been prepared with the aid of

A. D. EDMONSTON, *Principal Assistant.*

Chief Assistants.

T. B. WADDELL
WM. S. POST
A. N. BURCH
GERALD JONES
PERCY JONES
A. M. WELLS
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T. Neuman
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U. B. Gilroy
L. N. Clinton
C. W. Roberts
Laura Munson
Thomas Claussen
B. A. Reber
A. W. Reber
L. E. Anderson
P. T. Alexander
C. F. Marshall
Wm. J. O'Connell
H. M. Sturges
Harold White
F. L. Blair
Oscar Blumberg
J. R. Jahn
D. S. Hays
A. P. Bosworth
J. R. Meskimmons
W. A. Dorcas
H. Gerharz
J. H. Knapp
M. H. Blote
P. H. Lovering
Thomas Lewis
W. R. McLean
P. W. Porter
H. N. Sulliger
V. Givan
J. H. McCormick

Delineators.

Jos. T. Maguire
E. N. Sawtelle
C. L. Greene

Field Engineers and Topographers.

H. S. Williams
E. D. Stafford
J. F. Taylor
C. C. Vance
Glenn Lang
D. E. Frazier
F. L. Elam
J. H. Gibson
Millard Dawson
Ray Vernon
Ward Eisan

Engineering Aids.

F. L. Firebaugh
E. H. Ford
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Geo. Garlinghouse
C. R. Hagberg
C. A. Harper
Leslie Helgesson
D. J. Stout
J. G. Meyer
E. R. Hinnant
G. R. King
F. Monteleagre
Cleo C. Osborne
D. G. Spellman
Dewey Turner
G. Zucco
H. Neuman
R. H. Wight

FOREWORD.

This report, with its appendices, completes an investigation of the Water Resources of California commenced in 1921. It comprises a survey of water supplies and flood flows throughout the state, a determination of their characteristics, an estimate of the present and future needs for water, and the formulation of a comprehensive and coordinated plan for future development that will insure adequate water supplies for all purposes. Reports have already been rendered upon the work of the first four years. The material and data comprising this report are so voluminous that only a summary statement is contained herein. Details are given in separate volumes, appendices to this report, being prepared for publication as bulletins of the Division of Engineering and Irrigation, entitled, as follows:

Bul. 13—"The Development of the Upper Sacramento River."

Bul. 14—"The Control of Floods by Reservoirs."

Bul. 15—"The Coordinated Plan of Water Development in the Sacramento Valley."

Bul. 16—"The Coordinated Plan of Water Development in the San Joaquin Valley."

Bul. 17—"The Coordinated Plan of Water Development in Southern California."

Other bulletins pertaining to these investigations that have been published prior to this report are:

Bul. 4—"Water Resources of California." (A report to the Legislature of 1923 on the first two years of investigation.)

Bul. 5—"Flow in California Streams."

Bul. 6—"Water Requirements of California Lands."

Bul. 9—"A Supplemental Report on the Water Resources of California." (A report to the Legislature of 1925.)

Bul. 11—"Ground Water Resources of the Southern San Joaquin Valley."

The first appropriation for these investigations was made by the Legislature of 1921, Chapter 889 of the 1921 Statutes, in the amount of $200,000. This resulted in the publication of bulletins Nos. 4, 5, and 6. These contain a complete inventory of all the waters within the state's boundaries, an estimate of the future needs of water for all purposes, and a preliminary comprehensive plan for ultimate development that will secure the greatest public service from the state's limited water supply.

No provision was made for the continuance of the investigations by the 1923 Legislature but at the urgent request of the farmers of the southern San Joaquin Valley, the Chambers of Commerce of San Francisco and Los Angeles advanced $90,000 for the study of a first unit of the comprehensive plan that would relieve the stress in a section of the state most in need of an imported water supply. With this money, works were planned that would transport the surplus waters of the Sacramento drainage basin into the San Joaquin Valley and make a new supply available for the southern half of the valley. An account of this work is published in Bulletin No. 9, a report to the Legislature of 1925.

Chapter 477 of the 1925 statutes made $150,000 available to the Division for continuance of the work. With this money, the accompanying report and its appendices were prepared, concluding the investigation of the water resources of California.

CHAPTER 889.

STATUTES OF 1921.

An act to provide for the investigation by the State of California of the possibilities of the storage, control and diversion of water for public use and public protection in the State of California, and making an appropriation for said purpose.

[Approved June 3, 1921.]

The people of the State of California do enact as follows:

SECTION 1. It is hereby declared that the people of the State of California have a paramount interest in the use of all the waters of the state and that the State of California shall determine what waters of the state, surface and underground, can be converted to public use, or controlled for public protection.

SEC. 2. The state engineering department is hereby authorized and instructed to make the investigation in this act provided for and for the purposes herein specified.

SEC. 3. It shall be the duty of the state engineering department to determine the maximum amount of water which can be delivered to the maximum area of land, the maximum control of flood waters, the maximum storage of waters, the effects of deforestation and all possible and practicable uses for such waters in the State of California.

SEC. 4. It shall be the duty of the state engineering department to determine a comprehensive plan for the accomplishment of the maximum conservation, control, storage, distribution and application of all the waters of the state, and to estimate the cost of constructing dams, canals, reservoirs or other works necessary in carrying out this plan, and to report the result of such investigations with recommendations not later than the legislative session of 1923.

SEC. 5. In carrying out the provisions of this act the state engineering department is hereby authorized to examine any and all data, estimates and proposals in furtherance of the above purpose, according to its judgment of their engineering worth, and to cooperate with any department, bureau, office, service, or division of the United States, or of the State or counties, or with any municipality, irrigation, reclamation, conservation, drainage, flood control, levee, or other district agency for irrigation, reclamation, drainage, or flood control purposes, or for the development of hydro-electric power; or with any interested association, company or individual; *provided, further*, that the engineering department is hereby expressly authorized to accept, receive and use any funds or moneys contributed to it by any person, irrigation district, reclamation district, water and conservation district or any political subdivision of the State of California for the purpose of cooperating in the work aforesaid and carrying out the purposes of this act.

SEC. 6. With the approval of the governor, the state engineering department is hereby authorized to employ such assistance as in its judgment it may require and to incur such expense as may be necessary to carry out the purposes of this act. The governor is further authorized to appoint a consulting board, composed of citizens of special and technical qualifications, to serve in an advisory capacity, and without pay, in making the above investigation.

SEC. 7. There is hereby appropriated out of any money in the state treasury, not otherwise appropriated, the sum of two hundred thousand dollars, and made immediately available for any of the purposes of this act.

SEC. 8. This act shall not in any way be construed so as to deprive persons, corporations, or districts of vested rights.

SEC. 9. Any section or portion of a section of any act, statute or law of the State of California in conflict with the provisions of this act is hereby repealed.

CHAPTER 477.

STATUTES OF 1925.

An act to provide for the investigation by the State of California of the possibilities of coordinating the development of the water resources of the state for public protection and to the end that they may be put to the greatest beneficial use, and making an appropriation for said purpose.

[I object to the item of two hundred fifty thousand dollars in section 9 and reduce the amount to one hundred fifty thousand dollars. With this reduction I approve the bill. Dated: May 23, 1925. FRIEND WM. RICHARDSON, *Governor.*]

The people of the State of California do enact as follows:

SECTION 1. It is hereby declared that the protection of the public interest in the development of the water resources of the State of California is of vital concern to the people of the State of California and that the State of California shall determine in what way the waters of the state, both surface and underground, should be developed for the greatest public benefit, or controlled for public protection.

SEC. 2. The division of engineering and irrigation of the department of public works is hereby authorized and instructed to make the investigation in this act provided for and for the purposes herein specified.

SEC. 3. It shall be the duty of the division of engineering and irrigation of the department of public works to investigate the amounts and location of all the waters of the state, both surface and underground, and to determine the amounts available for use; to investigate all possible uses of water; and to determine the future growth of these demands and the works necessary for the accomplishment of the greatest use of the state's waters for all purposes; also to investigate the occurrence of floods and the works necessary for their control.

SEC. 4. It shall be the duty of the division of engineering and irrigation of the department of public works to ascertain the bounds of the agricultural lands of the state and the amounts of water required to bring them to maximum productivity, their economic source of irrigation supply, and the value of delivery of water to the land; to ascertain the amounts of water required for municipal and industrial purposes and for the generation of hydro-electric energy and for all other practicable uses and the economic source of supplies for all these purposes.

SEC. 5. It shall be the duty of the division of engineering and irrigation of the department of public works to study the coordination of all possible uses of water to the end that a full supply may be obtained as nearly as possible for all purposes with the greatest degree of public economy and to determine a comprehensive plan for the accomplishment of these purposes with the maximum conservation, control, storage, distribution and application of all the waters of the state and to estimate the cost of the necessary works and structures for carrying out this plan and to make all such studies, do all work, make all investigations, compile all data required to determine the manner in which the water resources of the state should be developed for their greatest use and public benefit.

SEC. 6. It shall be the duty of the division of engineering and irrigation of the department of public works, to prepare a printed report setting forth the results of these investigations with recommendations for a public policy for the development and conservation of the water resources of the state, not later than the first day of January, 1927.

SEC. 7. The division of engineering and irrigation of the department of public works in carrying out the provisions of this act, is hereby authorized to examine any and all data, estimates and proposals in furtherance of the above purpose, according to its judgment of their engineering worth, and to consult with and accept the work of any department, bureau, office, service, or division of the United States, or of the state or counties, or with any municipality, irrigation, reclamation, conservation, drainage, flood control, levee, or other district agency for irrigation, reclamation, drainage, or flood control purposes, or for the development of hydro-electric power; or with any interested association, company or individual; *provided, further*, that the division of engineering and irrigation of the department of public works is hereby expressly authorized to accept, receive and use any funds or moneys contributed to it by any irrigation district, reclamation district, water and conservation district or any political subdivision of the State of California for the purpose of cooperating in the work aforesaid and carrying out the purposes of this act.

SEC. 8. The division of engineering and irrigation of the department of public works is hereby authorized, with the approval of the governor, to employ such assistance as in its judgment it may require and to incur such expense as may be necessary to carry out the purposes of this act. The governor is further authorized to appoint a consulting board, composed of representative citizens, to serve in an advisory capacity in preparing the above report.

SEC. 9. There is hereby appropriated out of any money in the state treasury, not otherwise appropriated, the sum of two hundred fifty thousand dollars, and made immediately available for any of the purposes of this act.

SEC. 10. This act shall not in any way be construed so as to deprive persons, corporations, or districts of vested rights.

SEC. 11. Any section or portion of a section of any act, statute, or law of the State of California in conflict with the provisions of this act is hereby repealed.

SUMMARY REPORT.*

WATER RESOURCES OF CALIFORNIA.

California, extending for eight hundred miles along the Pacific shore of the United States, enjoys a moderate and pleasing climate favorable for human activity. The forests and minerals of its mountains, the fertile soils of its valleys, and the commercial potentialities of its seaports destine this state to advance in wealth and population until the exhaustion of some of life's necessities imposes a limit upon further expansion. With spacious areas of flat lands at low elevations, there is much smooth and accessible ground suitable for habitation. Natural resources for supporting man's activities, excepting water, are near at hand in abundance.

The water supply of this great state is derived from its annual drenching by rain and snow. Falling with greatest intensity upon the mountain areas, these upland regions constitute expansive collectors of precipitation which concentrates in stream-channels and flows to the ocean, passing by on the way the lower lying lands favorable for human occupation. Once a year the short winters wet the mountains and lowlands alike so that the bulk of the flow in California's streams occurs at the time of least demand for water. Three-fourths of all the state's waters reach the ocean within forty-five days after the time of their precipitation as rain or snow upon the mountain areas. The long, warm, almost rainless summers require water in large quantities for all human en-

*A full description of the geography, land and water resources of California and matters pertaining thereto, together with a preliminary comprehensive plan for their development, is contained in previously published reports of the Division of Engineering and Irrigation as follows:

Bul. No. 4, Water Resources of California.
Bul. No. 5, Flow in California Streams.
Bul. No. 6, Irrigation Requirements of California Lands.
Bul. No. 9, Supplemental Report on Water Resources of California.

deavors, but the summer flow in the streams, most valued of all, is only the drain water in wake of the great volume of winter and spring run-off. Those streams to which even the highest mountain areas are tributary, are well sustained by melting snow only through the first half of the summer months.

Practically all the summer flow of California's streams that are accessible, is now in use. Further advancement is attendant upon the construction of reservoirs that will make available for use at the needed time, the great volume of winter and spring run-off of normal years. Including this, ample water originates within the state's boundaries for all future needs but it is very unequally distributed geographically. Three-fourths of all this water lies within the northerly third of the state's area, while three-fourths of the need for water lies in the southerly two-thirds of the state's area. There is some water available to California in addition to that originating within the state's boundaries in the Colorado and Klamath River systems. Of these, however, the Colorado River is the only one geographically situated to alleviate the very unequal distribution of the waters. This survey of the available waters and of the future needs for water shows that full development of the latent resources of California can be attained only through the storage and distribution of water in accordance with some comprehensive plan, embracing both state and interstate streams, that will overcome the very unequal geographic distribution of the state's waters and that will insure adequate supplies for all localities.

CHARACTERISTICS OF A COMPREHENSIVE PLAN.

The agricultural lands, by reason of their flatter topography, their temperate climate, and their accessibility, are most suitable of all the state's lands for habitation. Except for areas about the state's seaports, the urban communities of the future must largely spread over lands

now classed as agricultural. Since cities of fairly mature growth use water about equal in amount to that required for irrigating crops on the same area, a plan that will provide an adequate allotment of water for all the agricultural lands, together with additional amounts for urban expansion about the state's seaports, will meet the future demands for water in the maximum development of the state's resources.

At the present time, ninety-six per cent of the water consumed in California is utilized in irrigating farm lands. This ratio will continue to be large for many generations because the growth of municipal areas relative to areas farmed, must necessarily be slow. The principal features of a comprehensive plan, therefore, must revolve about the greatly preponderant need of water for agriculture. However, the importance of municipal, industrial, navigation, hydro-electric and mining uses in the future growth of the state requires liberal provision for their needs.

Fortunately the agricultural, municipal, industrial and navigation uses will expand upon areas of low elevation, for three-fifths of the agricultural lands are less than five hundred feet above sea level. The mining and hydro-electric uses will expand in the mountainous regions that rise above the agricultural lands. Since these mountain uses of water return to the stream channels practically the full amount diverted, reservoirs to re-regulate the flow situated at levels intermediate between the agricultural and the mountain areas, will permit the unrestricted development of hydro-electric power and mining in harmony with a complete re-use of the same water on the plains below. Large reservoirs at these intermediate elevations, therefore, are important features of a comprehensive plan to secure the greatest use from the state's waters.

IMPORTANCE OF ORDERLY DEVELOPMENT.

It may be observed in traveling about the state that cities and towns do not flourish where water is deficient. The most prosperous centers of population are those enjoying ample water for both the municipal and adjacent country areas. In a state whose potential wealth, whether derived from industry in the cities or the cultivation of country lands, can only be realized in its full munificence through the artificial development of water supplies, there can be no greater subject for consideration than the creation of a state water policy designed to secure an orderly development of its water resources for the greatest public benefit.

NECESSITY OF ACTION.

Since the easily developed waters are now practically all in use, the future must spend greater sums for water than has been necessary in the past. Following the present incoordinate procedure, the costs of securing additional water in localities of short supply will be large and will become prohibitive as local supplies are exhausted. The expanding population of these communities will then seek more favored localities, either within or without the state's borders. As the unfavorable conditions spread to greater areas the loss to the state will increase rapidly, for only the northerly half of the state has ample water for future local use.

The approach to exhaustion of local supplies in many parts of California presents even more serious aspects than the loss of anticipated wealth through curtailment of expansion. Large areas deriving their supply from underground sources are facing a dropping ground-water plane. These areas are extending as their communities expand. Without additional supplies, well levels in these regions will continue to drop until either the underground basins are exhausted or the cost of pumping water to the ground

surface exceeds its value. For the most part, these areas of dropping ground-water plane are only partially developed and are without additional local supplies. Their natural expansion, therefore, will unavoidably destroy the values of their established properties and convert them into decadent communities.

A series of wet years might afford temporary relief to the regions of dropping ground-water plane as well as to other areas of acute water problems; however, unless plans for permanent relief are perfected during the surcease, the disaster will be the greater for the next succeeding dry years will be entered upon with increased demands for water but no greater supply. The prosperity of any part of this great state should not rest even temporarily upon the chance occurrence of greater-than-normal years. Works to relieve these communities are extensive in their character and involve many difficulties. They cannot be executed without long preparation. To defer action, therefore, is to invite future disaster.

Much has recently been said about converting agriculture from a "gamble" into a "business" so that farming may be as other industries. This would be done through diversification of crops and control of production. The diversification of crops and control of production can only be attained in localities where irrigation water is available as needed in all seasons of the year. Variability in the water supply forces the selection of crops best adapted to expected shortages. Uncertainty in supply forces the farmer to gamble on the occurrence of stream flow and prohibits the control of production.

Not over two-thirds of the area now under irrigation in California can obtain water as needed with reasonable certainty. Large areas of the state's irrigated lands have been planted to crops most suited to the irregular character of their water supplies and suffer the losses contingent upon variable soil moisture. The perfection of controlled supplies is under way in many communities

that can afford the cost. However inadequate local sources, the heavy costs of regulating last increments of stream flow, and conflicting claims to water rights, make progress slow. Progress would be facilitated by the adoption of a comprehensive plan that would ultimately furnish with reasonable certainty, adequate supplies to all localities throughout the growing season.

VALUE OF COORDINATED DEVELOPMENT.

The cost of carrying out a comprehensive plan that would permit the agricultural industry to operate as a business and that would remove the limitations of development on half of the area of this state, would be large; yet, there is no alternative if these objectives are to be attained. The costs may be minimized, however, by coordination of the development of water for all purposes. Through this means the cost of conflict may be removed, the cost of duplicate works may be eliminated, the cost of expensive reconstruction may be avoided as works are enlarged, and the greatest re-use of water may be secured. This report is the first to present the advantages of coordinated effort. It is believed that through this means only can values be created commensurate with the large costs of a comprehensive plan, and that possibly through this means the state may enjoy advantages not heretofore believed possible.

THE COORDINATED PLAN.

As directed by your honorable body in Chapter 477 of the 1925 Statutes, the Division of Engineering and Irrigation, State Department of Public Works, has prepared a coordinated plan for the development of the waters in the major geographic divisions of the state. This plan provides for the storage of flood waters for conservation purposes, the transportation of surplus waters of the Sacramento drainage basin to the deficient areas in the

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COORDINATED PLAN

FOR

DEVELOPMENT OF WATER RESOURCES OF CALIFORNIA

AS REPORTED TO

THE LEGISLATURE OF 1927

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San Joaquin Valley, an adequate summer flow in the Sacramento River for navigation and salt water control, the resumption of hydraulic mining in the Sierra Nevada Mountains, the control of floods by reservoirs, the expansion of irrigation along the lower Colorado River in southeastern California, and the diversion of water from that river to the Pacific slope for municipal purposes. All sections could not be considered because of the limitations of time and money. However, any policy that may result from this report should be extended to all parts of the state.

A general description of the plan follows in this report. The volume of pertinent engineering data and detail dimensions is contained in separate appendices,* one for each geographic section of the state.

THE SACRAMENTO VALLEY.

The Sacramento Valley, 170 miles long and 30 miles wide, contains 2,900,000 acres of agricultural land on the valley floor and 2,300,000 acres in its marginal plains and foothills. This valley has been growing rapidly. About 1,000,000 acres are now under irrigation systems, mostly on the valley floor. The expansion of irrigation has absorbed practically the entire summer flow of the river during the last several years of subnormal run-off, so much so, that for a time each season, navigation was seriously curtailed upstream from the city of Sacramento. The War Department issued warnings to the valley irrigators that sufficient water for navigation must be left in the river. In response, the irrigators organized a state supervisorship over their diversions to reduce them to a minimum quantity. A critical situation is approaching wherein the nec-

*A detailed description of the coordinated plan with engineering data is in preparation for publication in bulletins of the Division of Engineering and Irrigation as follows: Bul. No. 15, "The Coordinated Plan of Water Development in the Sacramento Valley." Bul. No. 16, "The Coordinated Plan of Water Development in the San Joaquin Valley." Bul. No. 17, "The Coordinated Plan of Water Development in Southern California."

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San Joaquin Valley, an adequate summer flow in the Sacramento River for navigation and salt water control, the resumption of hydraulic mining in the Sierra Nevada Mountains, the control of floods by reservoirs, the expansion of irrigation along the lower Colorado River in southeastern California, and the diversion of water from that river to the Pacific slope for municipal purposes. All sections could not be considered because of the limitations of time and money. However, any policy that may result from this report should be extended to all parts of the state.

A general description of the plan follows in this report. The volume of pertinent engineering data and detail dimensions is contained in separate appendices,* one for each geographic section of the state.

THE SACRAMENTO VALLEY.

The Sacramento Valley, 170 miles long and 30 miles wide, contains 2,900,000 acres of agricultural land on the valley floor and 2,300,000 acres in its marginal plains and foothills. This valley has been growing rapidly. About 1,000,000 acres are now under irrigation systems, mostly on the valley floor. The expansion of irrigation has absorbed practically the entire summer flow of the river during the last several years of subnormal run-off, so much so, that for a time each season, navigation was seriously curtailed upstream from the city of Sacramento. The War Department issued warnings to the valley irrigators that sufficient water for navigation must be left in the river. In response, the irrigators organized a state supervisorship over their diversions to reduce them to a minimum quantity. A critical situation is approaching wherein the nec-

*A detailed description of the coordinated plan with engineering data is in preparation for publication in bulletins of the Division of Engineering and Irrigation as follows: Bul. No. 15, "The Coordinated Plan of Water Development in the Sacramento Valley." Bul. No. 16, "The Coordinated Plan of Water Development in the San Joaquin Valley." Bul. No. 17, "The Coordinated Plan of Water Development in Southern California."

essary appropriation of water for irrigation is conflicting with the national jurisdiction over navigation.

Further difficulties arise near the mouth of the river. The diminished low water flow of the Sacramento River has been insufficient to hold back the salt water of Suisun Bay. For a period each season, the sweep of the tide through the channels of the delta region at the mouth of the river, carries in salt water from Suisun Bay that mixes with the fresh water of the river. As the summer flow in the river decreases, the menace of salty water becomes more serious in the channels from which the delta lands have habitually obtained their supply. These threatened lands are some of the most fertile in the state.

Although the unused summer flow of the Sacramento River is rapidly diminishing, the winter and spring flow is large. In their natural state, these waters overflowed large areas along the river. In 1911 the state legislature and in 1917 the national congress adopted a general plan of reclamation by which channels and by-passes lead this flood water in Suisun Bay without inundating the valley floor. These channels are wide due to the great flood flows of the Sacramento River. They take up much room and will constitute increasingly awkward barriers to traffic as the valley becomes more thickly populated. Although some of these channels and by-passes are already constructed, nevertheless, reduction in the size of floods would afford greater margins of safety and, on those channels not yet constructed, the widths could be materially decreased. Floods can be reduced in size only through their control by reservoirs. Therefore, at this time when the construction of reservoirs is necessary in order that agriculture may continue to expand in the Sacramento Valley, it is appropriate that the control of floods by reservoirs should receive consideration.

Attention should also be given in a program of reservoir construction to the rejuvenation of hydraulic mining. On January 7, 1884, a decision of a Federal Court prohibited further hydraulic mining in California because the debris

dumped in the stream channels was washing down on to the farm lands of the Sacramento Valley floor. Although later congressional enactments provided for the resumption of hydraulic mining under restrictions, the 1000 million cubic yards of gold-bearing gravels in the Sierra foothills remain unmined. It would mean much to the state to revive this industry and much to the nation to increase its gold production. In order that this industry may be revived, it is necessary to place barriers in the stream channels to restrain the debris from reaching the valley floor. Reservoirs constructed for conservation purposes may be so used. If these are located on the lower reaches of the streams, several years will pass before the debris will work its way down the stream channels to lodge in or near the upper edge of the reservoirs. Much of it would pile up at their margins or fill the channels for a distance upstream. Other material would lodge in the channels before reaching them. Such material would not impair their capacity. Reservoirs employed as debris barriers, therefore, would maintain their full conservation values for many years after mining started and would never have their capacity impaired to the full extent of the volume of mining debris dumped into the stream channels above them.

The coordinated plan for the Sacramento Valley comprehends the solution of all these public problems, water for navigation and salt water control, the reduction of flood flows, and the restraint of mining debris, while at the same time providing for the increasing demands for irrigation water through the construction of a large reservoir on the Sacramento River, one on each of its main tributaries, and the diversion of the upper portion of the Trinity River into the Sacramento drainage basin. These reservoirs are all located in the foothills near the edge of the valley floor. In this position, with almost the entire watershed tributary to them, they are admirably situated for the control of floods and the storage of mining debris as well as for conserving flood water for irrigation. Also, in

this strategic position, they separate the mountain and valley use of water, permitting each to proceed as best suits its needs without conflict, and so secure the maximum public service from the state's limited water supply. Lastly, they occupy the sites of least cost for the many advantages obtained.

The units of a coordinated construction program comprise a high dam near Kennett on the Upper Sacramento River, one on the Feather River near Oroville, one on the Yuba River near Smartsville, one on the Bear River near the state highway crossing, and one on the American River near Folsom. The Trinity River diversion would introduce a new supply from the Klamath River system into the Sacramento Valley. These would each be integral parts of the comprehensive plan for ultimate development, could be constructed progressively, and would provide sufficient water to meet all the increase in demands of navigation, of salt water control and of conservation during the next half century if operated in accordance with the plan herein presented. The reservoir capacities of these units are adequate to reduce floods and, on those streams on which placer gravels exist, to restrain mining debris for many years without interference with their conservation values. Also a large amount of electric power could be generated at the dams.

In preparing this coordinated plan, special attention has been placed upon devising a safe procedure for the use of reservoirs for flood control without sacrifice of their conservation values. Heretofore, it has been considered impossible to use the same space for the two purposes, because for flood control it should be held empty during the season of large run-off in readiness to absorb flood flows, while for conservation it should be allowed to fill while the water is available. After elaborate research to determine the characteristics of floods, a method has been evolved whereby the space reserved for flood control can be safely released in time to fill for conservation as the season progresses.

The application of these principles to the operation of the series of proposed reservoirs in the Sacramento Valley would effect a marked reduction in the flood flows in all the large tributaries as well as in the main channel. On the Upper Sacramento, the flood flow would be cut to half the maximum, a reduction that would make it feasible to reclaim Butte Basin, if desired. On the Feather, Yuba and Bear rivers, floods would be controlled to two-thirds their maximum volume. This reduction would permit reclamation along the Feather River to be completed without much additional levee construction and with the use of the present levee alignments except for a mile or two in a particularly restricted section of channel below Marysville. On the American River, the Folsom reservoir operated under this plan, would limit floods on this tributary to a flow that could be confined between levees on the banks of the present river channel. The cities of Sacramento and of North Sacramento could then expand to the river's edge and so eliminate the awkwardness of the present crossing that spans a wide area of overflow land between them.

Since power is the most readily marketable product of the reservoir system, the plan proposes to operate these reservoirs for the first period of years in a manner that will produce the greatest revenue from power. The block of power generated at these reservoirs should produce a substantial income if successfully marketed. The output is large. Including the Trinity River diversion, it is about equal to the present total production of power in northern California. To sell this large block of power will require skill in laying out the construction program and the complete cooperation of every marketing agency. Without this cooperation, a program as herein described would be wholly impracticable. With this cooperation, the sale of power could do much toward carrying the construction costs.

In proposing to operate this system of reservoirs for the first period of years to obtain the greater power rev-

enue, the other benefits to be derived from their construction would not be neglected. Through the program of reservoir operation devised by these investigations, the flood control values could be secured without material interference with the generation of power. The water from the tail-race of power plants would be ample for navigation, irrigation and salt water control for a long time. On the streams on which placer gravels exist, the accumulation of mining debris in the reservoirs, in being slow and not affecting the power drop at the dam, would not materially affect the power output.

At the end of the period of operation for greatest power revenue, the system of operating the reservoirs would be gradually changed to that producing the largest flow regulated for irrigation purposes. This change in the method of operation would about double the summer flow yield of the reservoirs. Power could still be generated, but being largely seasonal power, could only be marketed in part. Following this scheme, the summer flow in the Sacramento River could be adequately maintained for all purposes in the face of increasing diversions for the next half century.

The realization of such a program would be of inestimable value to navigation, salt water control, mining, flood control, irrigation and farming in general. It would secure for the present day the great advantages of a substantial summer flow in the Sacramento River for navigation, the advantages of salt water control in the delta region, the rejuvenation of hydraulic placer mining, and a substantial reduction in the flood flows. None of these could be obtained in nearly such full measure for years to come except through a coordinated program of development. These advantages all have such real and substantial value that earnest consideration should be given to the recommendations contained in this report.

The probable costs of the units of the coordinated plan, including spillways, gates, sluices, tunnels, conduits and

power plants required to accomplish the results described herein, are:

Unit	Stream	Height of dam, feet	Capacity of reservoir, acre-feet	Total cost
Kennett Reservoir	Upper Sacramento	420	2,900,000	$80,000,000
Oroville Reservoir	Feather	300	345,000	35,000,000
Narrows Reservoir	Yuba	435	445,000	30,000,000
Parker Reservoir	Bear	250	100,000	6,000,000
Folsom Reservoir	American	190	307,000	11,000,000
Fairview Reservoir	Trinity	370	1,400,000	*46,000,000
Total				$208,000,000

*Includes cost of completely developing the power drop from the Fairview reservoir on the Trinity River to the Sacramento River.

The plan does not include the construction of canals for distributing the water developed by these reservoirs, although studies have been made of alternate layouts. In general, the public advantage of following one particular scheme of canal construction was not found to be large. It is believed that this part of the program can be most effectively carried out by local effort as necessity arises. Therefore, the plan for the Sacramento Valley is confined to the production of a full supply of water in the stream channels in a way that will secure the maximum public service from these waters at the least expense.

THE SAN JOAQUIN VALLEY.

The San Joaquin Valley, 250 miles long and 40 miles wide, comprises the largest continuous block of agricultural land in the state. On the vast plains of the valley floor are 6,600,000 acres of land having gentle slope and flat surface conformation favorable for agriculture. The marginal foothills to the east and south add 1,800,000 acres more, making a total of 8,400,000 acres of agricultural land in the San Joaquin Valley, one-third of all the agricultural lands in the state.

Favorable conditions for growing crops, other than scant rainfall, have made this valley a pioneer section in

irrigation. One-half of the lands now under irrigation in California are in the San Joaquin Valley. Much of this land has an imperfect water supply. Some receives little or no water in dry years, other areas receive only a partial supply, and over half of the projects are short of water during the late summer months. Less than half of the area under irrigation has an adequate water supply throughout all seasons. Nevertheless, this development is utilizing all the low-water flow of the streams in the northern half of the valley and four-fifths of the entire run-off of the streams in the southern half.

The perfection of supplies in the northern half of the valley concerns principally the preparation of suitable economic plans for constructing storage reservoirs to hold over winter and spring flood waters for summer use. This has already been done or is now in progress on most of the projects in the northern half of the valley. In the southern half, however, the perfection of present inadequate supplies necessitates the importation of large amounts of new water that presents problems insurmountable to local effort. Here more than four-fifths of the mean flow of the streams is now in use although no reservoirs have been constructed. The irregular diversions from the rivers are supplemented by pumping from underground sources on one-third of the irrigated lands while on another third the entire supply is derived from wells. Favored with large areas overlying excellent supplies of underground water,* the southern San Joaquin Valley has enjoyed an attractive source of water easy for individuals to develop. So encouraged, extensive communities dependent upon irrigated agriculture have come into being. Their wealth is reflected in their assessed valuation that shows a greater investment in rural improvements than any other section of the state excepting properties adjacent to our largest cities.

*For detailed description see Bul. No. 11 of the Division of Engineering and Irrigation, "Ground Waters of the Southern San Joaquin Valley."

Although intensive development is in progress, there is still much good land in these communities without an adequate water supply. Nevertheless, so extensive is the use of underground water that the water plane is receding in many places. Experience is demonstrating that these underground supplies are not sufficient for the full development of the overlying lands so that at some point in the progress of expansion, the draft from the underground waters must exceed their average supply. There are now about half a million acres in the southern San Joaquin Valley supporting prosperous communities, that are either overdrawing their underground supplies or are approaching this condition. These areas are constantly growing larger. Their available surface supplies are already put to full use. Therefore, new water from some outside source is essential for continued growth and prosperity. Without it, the level of the underground waters upon which the southern half of the valley is so dependent, must permanently recede over extending areas until the profit in farming is entirely consumed in pumping the irrigation supplies to the ground surface.

The complication in the approach to exhaustion of the water supply in the southern San Joaquin Valley is of state-wide concern for there is no simple means of relief. There is no way to stop the sinking of new wells. All the overlying lands have the legal right to pump from the underground sources if they choose. The construction of storage reservoirs on local streams would help temporarily but little new water would be created thereby because four-fifths of the mean flow in the streams is already in use. The principal value of storage reservoirs would be in effecting a controlled supply. Unused water in other parts of the San Joaquin Valley is not available for the southern half, because there are areas of deficient supply close at hand to the few regions of surplus. The valley as a whole has little more than half enough water for its future needs. Therefore, a permanent solution to the water problem of the southern San Joaquin Valley can only be attained

by the importation of a large supply from some outside source.

The most accessible region of surplus is the Sacramento and upper Trinity drainage basins. Here is ample water, taken with the San Joaquin Valley streams, for the full development of both valleys. The complication and large cost of transporting the surplus waters of the Sacramento several hundred miles to the southern San Joaquin Valley, requires a comprehensive treatment of the problem. The coordinated plan proposes to correlate the conveyance of a new supply into the southern San Joaquin Valley with the development of water for local needs throughout the length of the two valleys. In this way the new supply may be obtained with full protection to established properties.

Accordingly, the new supply for the San Joaquin Valley would be derived from the water used to maintain navigation in the channel of the Sacramento River. After serving its useful purpose in the Sacramento Valley, this water would be diverted at the mouth of the river into the San Joaquin. Passing through the channels of the island region forming the delta of the Sacramento and San Joaquin Rivers, it would be boosted up the main channel of the San Joaquin by a series of pumping plants, each one pumping the water over a low dam to the higher level of the pond behind it. These dams would be collapsible so that they would not obstruct the channel during the flood season. They would be so located that, if desired, locks could be constructed along side them that would make the San Joaquin River navigable for a distance of 160 miles from its mouth.

This series of dams and pumping plants, extending the length of the main channel on the valley floor, would also constitute a means of conserving the scant water supply of the San Joaquin Valley. Water entering any section of the channel would be caught by these dams and redistributed throughout its length by the pumping plants. Thus water, entering the lower reaches of the channel that

often escapes into Suisun Bay, could be readily utilized by the greater area upon which it could be served.

The new supply of water obtained through the operation of these dams and pumping plants would be distributed to the lower lying lands in the San Joaquin Valley in order that the pumping lift may be a minimum. This would release San Joaquin water now used on these lower lands, at high elevations for diversion by gravity to the lands in the southern San Joaquin Valley that need more water. In this manner, the new supply could be obtained with a maximum pumping lift of 160 feet. The exchange of waters would save 340 feet of pumping lift. All plans for conducting the new supply directly to the higher lands that need water, either by gravity or by pumping, were found to be prohibitive in cost. The only plan of practicable proportions includes exchanges of water and involves properties extending the entire length of Sacramento and San Joaquin Valleys. The exchange of water is now practiced in several western states.

In diverting the water used for navigation in the Sacramento River to the San Joaquin, a certain portion would escape into Suisun Bay unless a physical barrier were constructed below the junction of the two rivers. Investigations of the cost of such a barrier have been completed recently in cooperation with the United States Bureau of Reclamation. These reveal that the probable cost would vary from $45,000,000 to $90,000,000 according to the site selected. This exceeds considerably the cost of developing the volume of water that would escape into Suisun Bay if no barrier were constructed. At some future time when this volume of escape water is needed for irrigation in the San Joaquin Valley, a physical barrier could be constructed in order to make it available. In the meantime, the escape of this water into Suisun Bay would automatically dispel the menace of incursion of salt water into the channels of the delta region. The volume of water desirable for navigation in the Sacramento River is ade-

quate for both salt water control and diversion into the San Joaquin Valley for a long time. Thus, the coordinated plan avoids the large cost of a barrier for many years to come.

In pumping the new supply from the Sacramento up the grade of the San Joaquin River, it will be necessary to construct levees along the banks of the river for a distance upstream from each dam in order to confine the water to the stream channel at its increased level. The required height of these levees would grow less as the next upstream dam is approached, until at some intermediate point, the ponded stream would be confined within the natural banks of the channel. The coordinated plan proposes to incorporate these levees in a general plan of reclamation for the overflow lands of the San Joaquin Valley.

Unlike the Sacramento Valley, the strip of overflow land in the San Joaquin is so narrow that the reservation of a channel large enough to pass the maximum flood, leaves an insufficient area benefited to pay for the cost of the levee system. Although much study has been placed on plans for reclaiming these overflow lands, an economic plan of complete reclamation has not yet been devised. However, opportunity is afforded by the coordinated plan to improve these conditions because the required width of flood channels could be reduced if the scheme of reservoir operation devised by these investigations, were applied to the reservoirs on the tributaries of the San Joaquin that are either already constructed or will be required to meet the demand of the next few years for irrigation water. These will have sufficient capacity to reduce flood volumes without interference with conservation, to nearly half their maximum flow except for the lower one-third of the main river channel. On this section some reduction could be effected but not as much as on the upper two-thirds of the channel.

At some later time, a greater degree of flood control can be effected on the San Joaquin River than here described.

The reservoirs now constructed and at present contemplated on its tributaries will not develop the entire run-off of these streams. Additional storage will have to be provided at some future time for conservation purposes. By including this additional storage in the flood control system, floods may be reduced to smaller volumes than described above. This additional storage is part of the comprehensive plan for the ultimate development of the San Joaquin Valley, but is not included in the units here suggested because it will be some time before it is needed for conservation purposes.

Large reservoir units, sufficient in size to make the entire run-off of the streams available in controlled supplies, are included in the coordinated plan for the southern part of the San Joaquin Valley. Such a large fraction of the entire stream flow is already utilized in this part of the valley, that, even by the construction of these large reservoirs, the new supplies made available would be sufficient to serve the normal growth for only a few years. However, they could temporarily relieve the stress caused by the overdraft on underground waters in the southern half of the valley.

The construction of these reservoirs would accomplish more than the development of some additional water and the delivery of completely controlled supplies. A very considerable amount of power could be generated as well. In order to generate the largest amount of power possible with an economic installation, the coordinated plan proposes that about one-fifth of the peak irrigation demand on the area served directly from the reservoirs, be supplied by pumping from the underground basins. By so doing, the draft on the reservoirs would be more nearly constant throughout the season and a greater output of salable power could be generated. Also, by pumping still greater volumes of water from the underground basins during years of subnormal run-off, completely regulated supplies could be delivered to the land with smaller reservoirs than otherwise would be needed. The coordinated

plan proposes that this be done to the extent that the total cost of completely regulated supplies would thereby be reduced. An exceptional opportunity exists for an economic arrangement of this character, for one-half of the area now receiving water from the rivers through canals is already equipped with wells and pumping plants.

These same reservoirs could easily be used for controlling floods. Their capacity would be sufficient, if operated under the plan herein proposed, to reduce floods to one-half their maximum flow without interference with their conservation functions.

Plans for constructing storage reservoirs on the Upper San Joaquin, Kings and Kern Rivers, the largest streams of the southern San Joaquin Valley, are now being perfected by water-storage and conservation districts. These are organizations of the many corporate units that now utilize water from these streams or desire to do so. The coordinated plan in no way conflicts with the plans of these districts. It is distinguished from them in providing for a more complete development than the studies of the districts indicate are desirable if the entire costs are assessed against the lands within the projects. The coordinated plan sets forth greater accomplishments for public consideration.

A series of trunk canals is included in the comprehensive plan for the ultimate development of the San Joaquin Valley. These canals would extend southerly, one from each main tributary of the San Joaquin River and one also, from the American River in the Sacramento Valley. They would divert at the highest practical elevation on the edge of the valley floor that would not involve expensive foothill construction. The function of these canals would be to feed the water from each tributary into systems of distribution canals at the highest possible elevation. This would take water now used in one system and deliver it to another system further south upon receipt of an equivalent amount from some other source. No exchange of ownership in supplies is suggested. Following this system, the

entire valley floor may ultimately be brought under irrigation with the maximum economy in pumping the new supply imported from the Sacramento Valley. Even with this economic arrangement, the pumping lift on much of the imported water that ultimately will be required to irrigate the entire valley floor, will be large.

Only two of these trunk canals will be needed for some time to come. These two take out from the upper San Joaquin River and the Kings River, respectively, and are necessary to convey a new supply into the area of dropping ground-water plane in the southern San Joaquin Valley. They are part of the first construction units of the coordinated plan for importing surplus Sacramento River water into the San Joaquin Valley. With these two canals in operation, new supplies could be delivered into the heart of the area that needs them.

The probable costs of the reservoirs of the coordinated plan in the southern San Joaquin Valley that will yield, in conjunction with the ground-water development already existent, completely regulated supplies of irrigation water, control floods to one-half their maximum values, and develop incidental hydro-electric power to the greatest economic extent, are:

Unit	Stream	Height of dam, feet	Capacity of reservoir, acre-feet	Total cost
Temperance Flat Reservoir	Upper San Joaquin	595	1,100,000	$51,000,000
Pine Flat Reservoir	Kings River	450	1,400,000	35,000,000
Isabella Reservoir	Kern River	250	1,100,000	40,000.000
Bakersfield Reservoir	Kern River	140	200,000	
Total				$126,000,000

The foregoing estimates include the cost of spillways, gates, sluices, tunnels, conduits and power plants required for conservation, flood control and power development. On the Kern River, the estimate includes conduits and power plants to develop the entire power drop through the Kern Canyon between the Isabella Reservoir and the Bakersfield Reservoir, exclusive of the capacity of the power plants now operating in the Kern River Canyon.

The probable cost of the first units of the coordinated plan for introducing a new supply from the Sacramento into the southern San Joaquin Valley, that will have a capacity of three thousand second-feet, the equivalent supply for 450,000 acres of new land, is:

Item	Cost
Dams and pumping plants on San Joaquin River complete with levees along river banks	$13,000,000
Canals extending southerly from Friant on upper San Joaquin River to Kings River and from Kings River southerly to near Earlimart	11,000,000
Total	$24,000,000

The foregoing estimate does not include the cost of the salt-water barrier that will undoubtedly be ultimately required nor any part of the cost of the coordinated plan in the Sacramento Valley that is necessary to make the surplus water of the Sacramento drainage basin available for diversion into the San Joaquin Valley, neither does the estimate of cost of the dams and pumping plants on the San Joaquin River include the cost of locks that would be necessary at each dam to render the river navigable.

SOUTHERN CALIFORNIA.

California, southerly from Tehachapi Pass, embraces twenty per cent of the area of the state that is favorable for human habitation, while but little over one per cent of the state's waters, exclusive of the Colorado River, are tributary thereto. Although possessing a disproportionately small share of the waters originating within the state's boundaries, these lands have experienced a rapidity of settlement and improvement that has amazed the entire world. Already one-fifth of the area possessing a water supply on the Pacific slope lies within the limits of incorporated cities and towns and this ratio is continuously growing larger. The relinquishment of agricultural land for urban use does not reduce the total water consumption, as cities of fairly mature growth use water in amounts about equal to that required for irrigating the same area. The demand for water, therefore, can never grow less in

southern California, but larger supplies will be needed for industries and manufactories within cities, and for the extension of agriculture to the limits of the available lands if supplies for this purpose can be found.

A survey of the available waters, both surface and underground, shows that four-fifths of the local supplies on the Pacific slope of southern California, excluding Owens Valley, are now in use. Utilizing four-fifths of the available local water, less than half of the favorable area is occupied by cities or towns and irrigated lands. In order that growth and expansion may continue to the full limit of the natural resources other than water, the Pacific slope of southern California will require three times the volume of water that can be obtained from nature's allotment to this territory. Unless this additional water can be secured, the future must face a curtailed growth incommensurate with the opportunities offered by the other natural endowments of this remarkable territory.

The development and use of the local supplies is attended not only by the usual complexities of the California water law but also by the problem of dropping ground-water plane similar to that of the southern San Joaquin Valley. The problem is serious because three-fourths of the local waters now in use are taken from underground sources. Observations of ground water levels during the years 1922 to 1925, show that drops have generally prevailed and that, in three seasons, the water plane has receded over large areas as much as fifteen to fifty feet. Although the greater values in southern California permit pumping from greater depths than in the San Joaquin Valley, nevertheless, the inadequacy of the underground supplies for the support of the full development of the overlying lands, results in a similar necessity for imported water. Unless large amounts of water can be so obtained, the southern communities must suffer from the destructive competition of pumping from underground sources that have a receding water-plane. Such competition will burden the com-

munities with prohibitive pumping costs and attendant loss in property values, and in the end reach their limit.

The threatened exhaustion of local waters has not occurred only through the foresight of Mr. William Mulholland, Chief Engineer of the Bureau of Water Works and Supply of the City of Los Angeles. Because of the importation of water from Owens Valley for the City of Los Angeles, there are still some local waters available for the expanding uses of adjacent territory. Further relief may be obtained by extending the Owens Valley project to include the waters of Mono Basin. However, a complete development of the surplus or unused water from these sources would import in total but a quarter of the water that will ultimately be desired for the Pacific slope of southern California in addition to their local supplies. Nevertheless, Owens Valley and Mono Basin are important sources of additional water, as they will be required ultimately in any event irrespective of the acquirement of other supplies. Studies have been pursued to find sources from which adequate supplies for the future may be secured. These investigations show that sufficient surplus water exists in California, only in the north Pacific Coast region six hundred miles distant and separated by mountain barriers that could be pierced only at costs beyond our present conception of possibilities.

In the absence of supplies sufficient for all future purposes, attention should be directed toward providing for municipal and domestic needs. The rapid rate at which lands, formerly agricultural, are being converted into urban and suburban properties in southern California, makes it difficult to distinguish between irrigation and potential domestic water. In fact, it appears that ultimately, practically the entire use of water on the Pacific slope will be urban or suburban in character. The pleasing climate of this section is attracting residential settlement from all the states of the Union that will be limited only by the available water supply. However, distinguishing between these two uses for the next third of a century,

an analysis of the past and present rate of increase in the demand for municipal water indicates that a continuous supply of fifteen hundred second feet will be required in addition to water in present use, to serve the normal expansion of the metropolitan areas of this region.

It is generally conceded in the division of the waters of the Colorado River that fifteen hundred second feet should be allotted to the Pacific Slope of southern California for municipal purposes. It is anticipated that this will become available with the passage of the Swing-Johnson bill for the construction of the Boulder Canyon dam on the Colorado River, now pending in congress. It is vitally important to the entire state, not only that this water should be secured for the cities and towns of the Pacific slope of southern California, but also that the advantages that will accrue from the construction of the Boulder Canyon dam in the control of floods and of the greater summer flow, should be obtained for the California lands bordering on the lower Colorado River.

The construction of the Boulder Canyon dam is one of the most important issues before the public at this time for the deficiency in the natural water supply of southern California and the control of floods on the lower Colorado River is a matter of serious concern. Although it is not apparent from what source the required large volumes of new water can be obtained for the full development of the Pacific slope, nevertheless, present attention should be directed towards securing those new supplies that are available on the Colorado River and elsewhere and in coordinating their use to obtain the greatest benefit from their limited amounts. In this effort, these investigations have cooperated to the fullest extent with the Bureau of Water Works and Supply of the City of Los Angeles in their projected plans. Data, analyses, and plans of accomplishment have been exchanged with this office. Separate and independent estimates of water requirements, of water supplies and of plans of development have been made and placed at its disposal.

In the study of local supplies, special attention has been placed upon the coordination of surface storage in reservoirs, the control of floods, and the replenishment of the underground basins from which such a large part of local water is obtained. The Los Angeles County Flood Control District has under way the construction of a series of twelve reservoirs for these purposes on the principal streams in Los Angeles County. Such reservoirs will be desirable on all local streams in southern California as growth continues. The intensive development in progress creates a particularly large flood hazard and makes the reservation of large flood channels undesirable. The reduction of flood flows by reservoirs is therefore very desirable.

Unfortunately, reservoirs on nearly all the streams are costly. One exception is at the Prado site near the entrance to the Santa Ana Canyon. Here large capacity can be obtained at fair costs. A reservoir at this point would control the floods of the Santa Ana River on the coastal plain and make available for use considerable amounts of flood water that now run into the ocean. A plan for the complete development and control of floods on the Santa Ana River is now in process of assembly through special investigations being carried out in cooperation with San Bernardino, Riverside and Orange counties. Reservoir sites have been selected on all the tributaries of the Santa Ana River at locations that would control the floods as they debouch on the valley floor. These sites are all more costly than the one at Prado; however, it is believed that their construction will become desirable.

The coordinated plan proposes that reservoirs be constructed on all the principal streams and that they be operated both for conservation and flood control. Although the total quantity of flood water reaching the ocean is relatively small, still it can be most effectively conserved by these methods. The principal storage of water would be in the large natural underground basins on the lower reaches of the streams where these are available. These

offer a splendid opportunity for cheap storage in many basins. However, some surface storage is necessary even in these instances in order to equalize the stream flow. In the natural state, flood waters rush down the channels in volumes too large for absorption by the underground basins. By reducing these flows through reservoir control, practically their entire volume could be introduced into the underground basins through absorption by the stream channels or by prepared spreading works.

The desirable capacities for these reservoirs have not been finally determined at the time of writing this summary report so that their cost can not be tabulated; however, they will be large. The coordinated plan will secure the greatest results from their use in the same manner as proposed in the coordinated plan for the Sacramento and San Joaquin valleys. By the application of the principles developed by these investigations for the combined use of reservoirs for conservation and flood control, the conservation value of their space will not be sacrificed for flood control. In this way the maximum results will be attained at minimum cost.

It is believed that these principles of reservoir operation for flood control can also be applied to the Boulder Canyon reservoir to advantage. Their application should result in a more effective utilization of the reservoir capacity than has been contemplated because they secure flood control without the sacrifice of any reservoir space. These principles will be fully set forth in an appendix* to this report.

*Bul. No. 14, "The Control of Floods by Reservoirs."

RECOMMENDATIONS.

California, endowed by nature with climate, soils, forests, minerals, and harbors favorable for an advanced civilization, is dependent, nevertheless, upon the artificial development of water-supplies for the complete fruition of its many advantages. At this time in the progress of expansion when all the easily developed supplies are now in use, it is of the greatest importance to every person and to every industry that expects to partake of the future prosperity of this state, to have assurance that progress shall not be arrested by the lack of adequate water supplies.

The creation of a state water policy that will insure to present and future generations the uncurtailed development of natural resources along sound and economic lines would be an outstanding achievement. The benefits would be far reaching. All activities are vitally concerned in water. Although the total requirements of agriculture greatly exceed those of industry and commerce, nevertheless, industry and commerce would indirectly reap the greater benefit. They will endure and expand most successfully in the midst of thriving agriculture. Agriculture in California requires large quantities of water. The total supply is limited and unequally distributed over the state.

This report presents an engineering plan whereby, through coordination of effort, those sections deficient in local supply may enjoy adequate water for agricultural and all other purposes. The new supplies for the deficient areas would be taken from regions of surplus after providing for their complete development. This plan is presented as the one containing the fewest difficulties in the attainment of the desired accomplishments. While only the major areas were considered in formulating the plan,

any policy that may result should extend to all parts of the state alike.

So extensive is the area, so many and varied are the interests, and so great are the expenditures involved in this plan that the usual method of procedure is impracticable. The economic, financial, legal and political problems relating to its execution are so complex and far reaching that they should be the subject of careful deliberation. The broad values and public advantages of the plan should be weighed with the costs and difficulties. Methods of execution, of operation and of financing should be considered along with the extent to which costs should be distributed. In view of the intricate nature of these problems and their momentous bearing upon the future of California, the Division and its advisors earnestly recommend that a committee representative of all those concerned in the development of the water resources of California, including national and state offices, be appointed solely for the purpose of determining first, the practicability of carrying out this plan, and second, if found to be practicable, to recommend a method of procedure.

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